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Otto F. Trout, Jr., and Paul R. Hill.

NASA Langley Research Center
Langley Station, Hampton, Va.

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HUMAN WORK PERFORMANCE IN SPACE

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NASA Langley Research Center
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SUMMARY: Methods of manual performance of extra-vehicular and intravehicular work in space are being investigated by means of simulation techniques in order to develop locomotion and restraint aids, equipment design data, and manual task procedures. Simulation and flight experiences to date have provided insight into problem areas for application to maintenance, repair, and assembly tasks during space-flight operations.

INTRODUCTION

How does man accomplish useful work in space, what are his capabilities, and how do we design spacecraft systems for the efficient performance of manual operations under weightless conditions? In order to answer these questions, NASA has been conducting advanced research and development on man's EVA and IVA capabilities. Conceptual studies of future space vehicles have also indicated that the economical accomplishment of extended flights requires a thorough understanding of human work performance as well as engineering data on man's biomechanical capabilities, physiological limitations, energy expenditure, and life support requirements. Therefore, in support of future missions, human factors research has been in progress for several years.

Data are being developed by the use of simulation techniques

supported by the actual EVA flight experience of the Gemini program. Simulation techniques, especially neutral buoyancy, have given us a powerful tool for the detailed examination of many EVA and IVA operations and have furnished valuable insight into human work performance in space.

ANALYSIS AND DATA

Two major factors degrade the astronaut's ability to work in space: first, the lack of traction due to gravity and, second, the reduced mobility, dexterity, and tactility caused by the pressurized suit. Considerable progress has been made in providing traction and developing new operational procedures through the use of simulation techniques. Progress in developing more

suitable pressure suits for working in zero gravity has been slow.

Traversal to the worksite is necessary at the beginning of any EVA task. Figure 1 shows a pressure-suited subject making egress through a transparent model of a space-vehicle air lock during neutral-buoyancy tests. Ingress-egress operations through air locks with various length-diameter ratios have been investigated to determine performance envelopes and modes of operation. Locomotion and turnaround in the air lock are accomplished by bracing between surfaces. Figure 2 shows the experimentally derived length-diameter performance envelopes between possible and impossible operation with the suit configuration shown in figure 1.

Means of locomotion about the exterior of the spacecraft have been investigated, including magnetic shoes, Velcro foot pads, ladders, handholds, and single and double handrails. Traversal by means of handrails has proven more practical than the other methods investigated but is not without difficulties. Figure 3 shows the astronaut traversing along a handrail under water in preparation for the Gemini XII mission. Operations of the subject with his body parallel to the handrail were complicated by a tendency to rotate about the handrail and by difficulty in maintaining body attitude parallel to it. In this case the procedure developed was to operate with the body perpendicular to the handrail.

Body attitude in yaw and roll are then controlled by simultaneous application of force with both hands. Better control of rotation about the handrail can be achieved if its cross section is oval or rectangular rather than circular. Locomotion procedures which proved successful during the neutral-buoyancy simulation training were equally successful in space. Where handrails can be provided for traversal about the exterior of the spacecraft, they are superior to reaction propulsion devices, which are less efficient and require storage and preparation outside the spacecraft.

Two approaches are available for the performance of work tasks. One is to place the astronaut in a coplaner orbit, provide him with a reaction propulsion unit for maneuvering, traversing, and materials transfer, and provide him with torqueless tools for his operations. The second approach is to provide him with adequate traction to accomplish the task in place.

For certain tasks, only a small amount of traction is necessary. Figure 4 shows a test subject assembling components of an antenna while operating from a semi-free-floating mode. Light tasks not requiring sustained application of force can be performed effectively in this manner, since the subject can intermittently correct body attitude and traverse by grasping elements of

the structure. This method has the advantage of requiring no other means of traction, but a safety line is necessary to prevent the subject from drifting from his worksite. By slow and deliberate operations, the astronaut can minimize the loads imparted to the structure. Thus, it may be possible for him to assemble lightweight structures in space which would not be able to support their own weight on the ground.

Where greater traction is required for the application of moderate forces or for the intermittent application of large forces, the astronaut's body must be restrained in some manner. Figure 5 shows the Gemini XII astronaut using a ratchet wrench on a bolt during neutral-buoyancy tests while restrained with a double waist tether similar to a window washer's belt. While using this restraint, he corrects body position by grasping a fixed object or handhold and by contacting the surface of the spacecraft with his hands and feet. This restraint system is not practical unless the astronaut can contact the spacecraft wall with his hands to control the pitch attitude of his body, and is not suitable for tasks requiring the use of two hands on a continuous basis. Excellent correlation was obtained with the neutral-buoyancy simulation of the task and the Gemini XII flight, since movements are sufficiently slow to be influenced very little by the damping effects of the water. A number of variations of the waist

tether have been tried. Rigid waist tethers are generally less advantageous than the flexible straps since they restrict movement about the worksite and are bulkier to carry.

Neither of the working modes previously described are satisfactory if it is necessary to apply large sustained forces. Stronger, more rigid restraints are then necessary. One solution is to restrain the feet in some manner to approximate the standup working mode at earth gravity. A number of different restraints have been investigated, including Velcro foot pads, foot stirrups, toe traps, ski footholds, and rigid foot restraints. Figure 6 shows the use of the familiar "Dutch shoes" on the final Gemini mission. This type of restraint allows the astronaut to apply large sustained forces or work freely with both hands on more intricate tasks. He is able to control his movement backward for 90° and to either side for 45°. However, he is restricted to a fixed worksite. Weightless-simulation experiments have indicated that the traction provided by this restraint system enables a man to manipulate masses up to several hundred pounds. This restraint system, however, has the disadvantage that it must be moved each time the worksite is changed or else an additional set of restraints must be provided.

The concept of a stationary worksite is illustrated in

figure 7. The astronaut assembles the components of a major structure from a fixed work platform. The structure is manipulated to new positions and reattached to the worksite as necessary to continue assembly.

For even larger assemblies in space, components could be managed from an articulated cage similar to a "cherry picker." Figure 8 shows experiments with a cage type of system from which the subject was able to work effectively under simulated weightless conditions. He braces himself within the cage and is restrained by a waist tether which prevents him from floating out.

Experiments in weightless simulations and during the Gemini flights indicate that most common handtools can be effectively used if they can be manipulated with the pressurized glove and if suitable restraints are used to provide traction. Means of retaining both the tools and fastening devices are required, and therefore the number of tools and parts should be kept to a minimum. Experiments with captured quick fasteners and self-aligning devices indicate that the assembly time can be reduced by a factor of up to 10.

The transport of large and bulky masses has been explored by simulation techniques. Manual transport of masses while traversing on a handrail is difficult because both hands are required for locomotion. Figure 9 shows the test subject moving a

150-pound mass by this method. A better, but not entirely satisfactory, technique is for the subject to carry the mass on his back. Figure 10 shows a summary of energy expenditure measurements during typical transport tasks, derived from portable metabolic measuring equipment carried in the backpack. Similar measurements are being made on various EVA tasks to determine the workloads.

Since all but a small percentage of the astronaut's time will be spent inside the spacecraft, research is being conducted on the various IVA work tasks. During IVA the astronaut's capability and dexterity will be greatly improved if he is not required to wear a pressurized suit. Floating away from his worksite will be less of a problem if the walls and equipment are close enough to provide traction.

The principles for manual performance of IVA tasks are similar to those for EVA work. Figure 11 shows a neutrally buoyant test subject free-floating while working in the interior of a mockup. Many light short-duration tasks can be performed by this mode of operation. Conveniently located handrails and closely spaced walls enhance the astronaut's ability to locomote, maneuver, and maintain his work position. The free-floating work mode is not suitable for tasks requiring sustained forces or for intricate

tasks requiring the use of two hands simultaneously.

As illustrated in figure 12, the use of the waist tether for IVA did not have any advantage over the free-floating mode when traction could be attained by contacting or bracing against interior walls. Small rooms or compartments are advantageous in spacecraft since they aid in working, traversing, and maneuvering. Utilization of cabin space can be more efficient than under gravity conditions since the astronaut is not restricted to an upright position.

For lengthy IVA tasks at a fixed worksite or for intricate tasks requiring the simultaneous use of both hands, foot restraints have proven advantageous.

Figure 13 shows a test subject using a set of flexible rubber toe traps while working at a bench. This mode allowed him to work on intricate tasks with a dexterity similar to that at earth gravity. Velcro foot pads were not satisfactory because they tore loose when the subject leaned backward and tried to right himself.

Figure 14 shows the subject working at a control console while seated in a chair with a safety belt during simulated weightlessness. This mode was satisfactory for working at a control console for long periods of time provided the controls were within his reach. In addition, intricate assembly-disassembly operations on small equipment can be accomplished in this mode.

Figure 15 shows the IVA test subject going through an exercise routine while suspended by a waist tether stretched between two walls. This method of exercising in a weightless state has the advantage that only minor disturbances are imparted to the spacecraft, even when the exercises are vigorous.

The use of tools in IVA tasks is similar to that in EVA except that they are easier to manipulate without the pressurized gloves. Tools and objects within the cabin need to be retained when not in use but need not be tethered as in EVA, since they can be recovered.

CONCLUDING REMARKS

Since each man-hour in space will cost thousands of dollars, it is necessary that human factors data be made available to the designers in handbook form, task procedures thoroughly developed and rehearsed, support hardware tested, and time lines developed by simulation techniques well in advance of the space flight. In addition, the astronauts should be trained through the use of simulation techniques to complete each assigned EVA and IVA operation.

A 4-minute movie will be shown to illustrate some of the tasks that have been discussed in this paper.

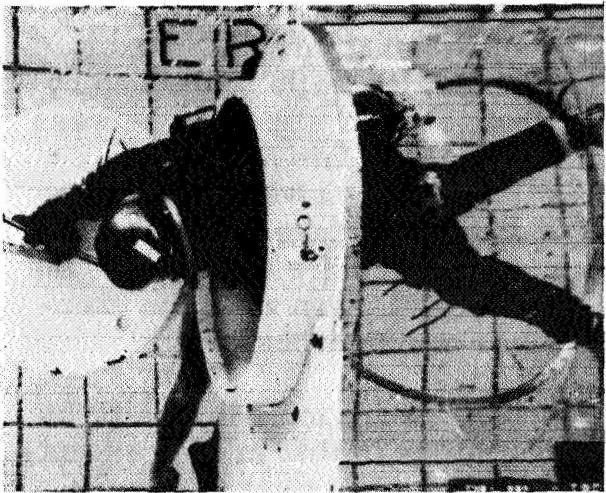


Figure 1.- Ingress - egress.

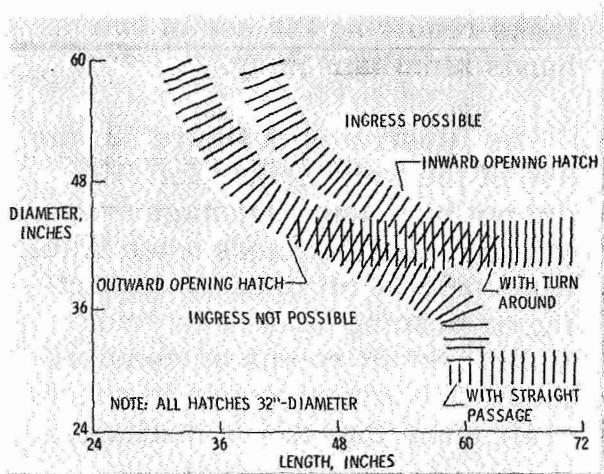


Figure 2.- Airlock dimensional limitations.

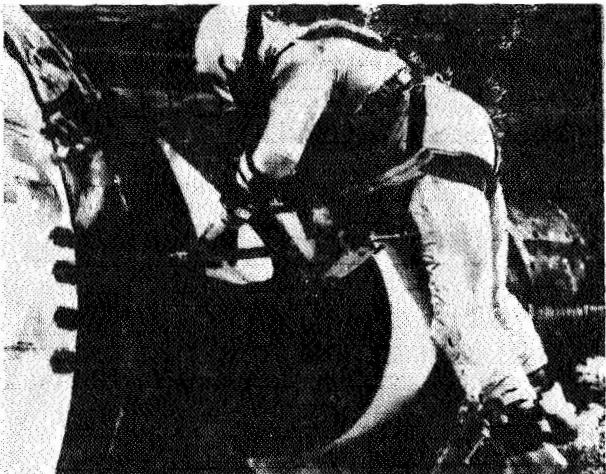


Figure 3.- Traversal on handrail.

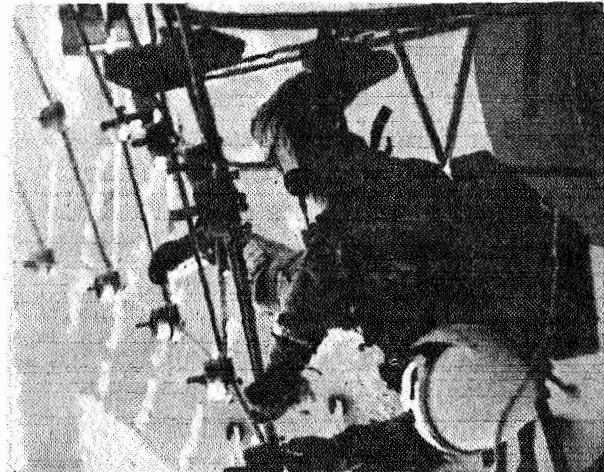


Figure 4.- Antenna assembly.

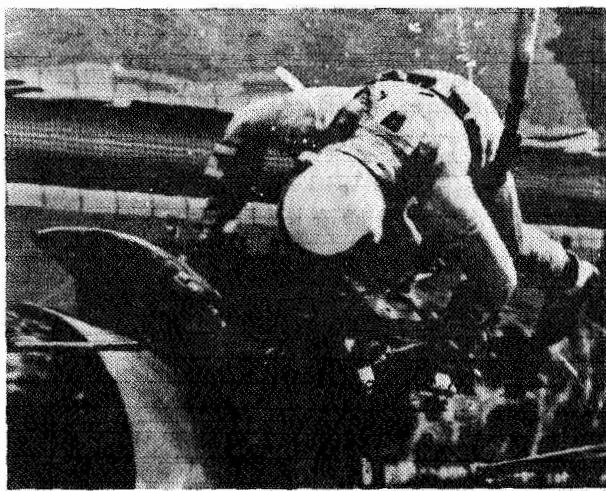


Figure 5.- Waist restraint.

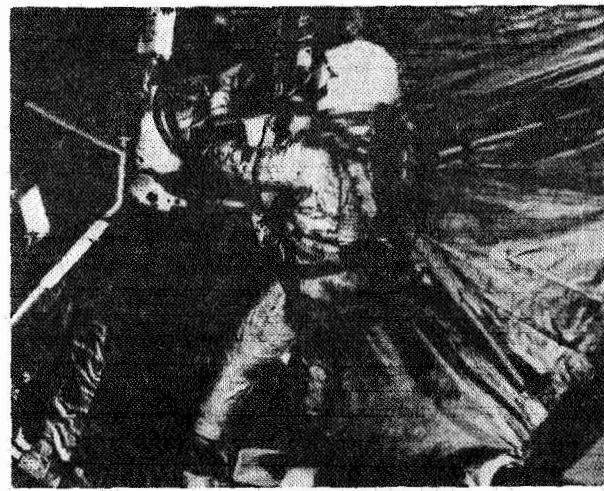


Figure 6.- Foot restraints.

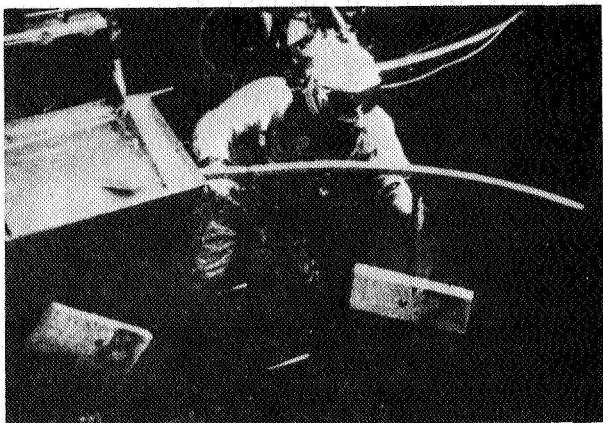


Figure 7.- Stationary worksite.

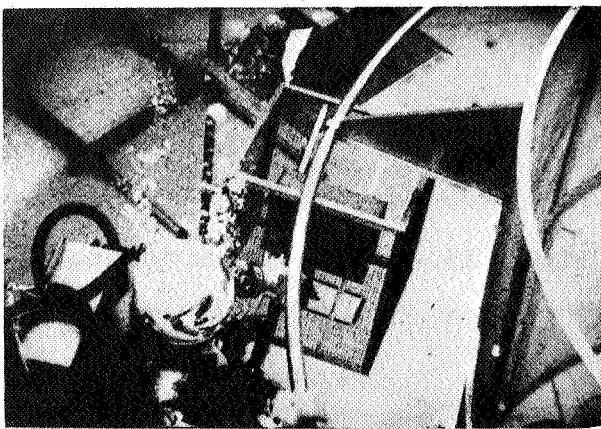


Figure 9.- Package transfer.

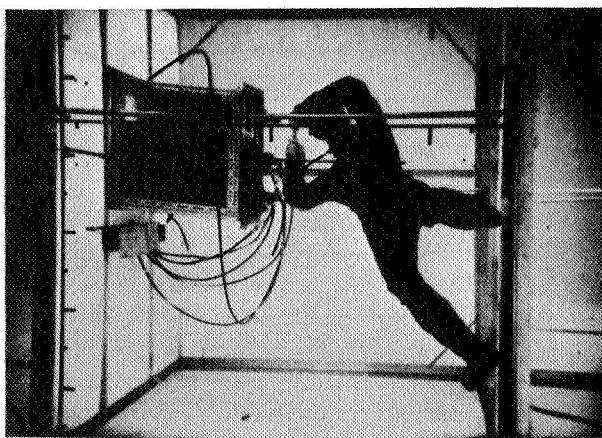


Figure 11.- IVA free-floating mode.

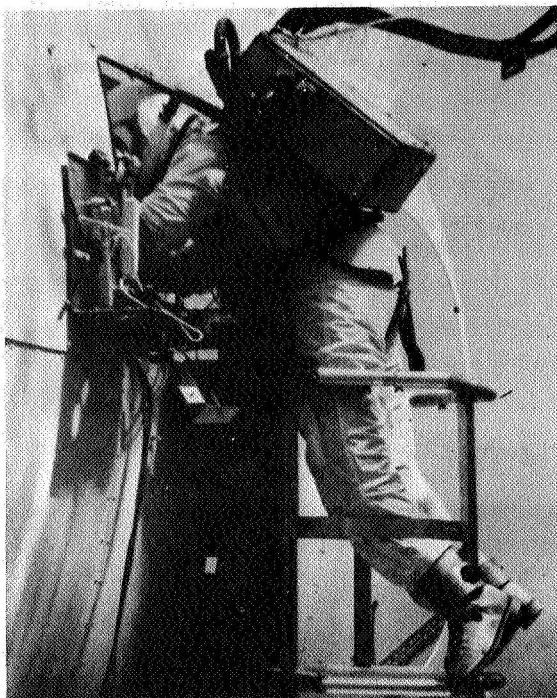


Figure 8.- Cage restraint.

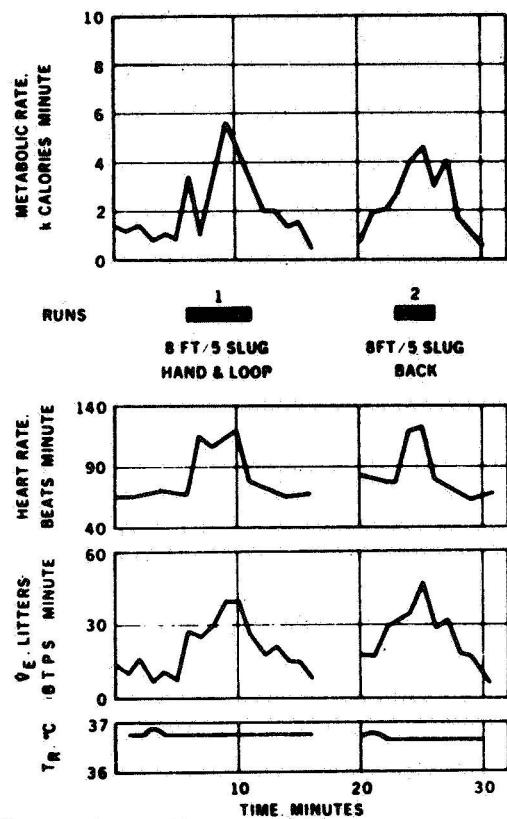


Figure 10.- Ergometric measurements.

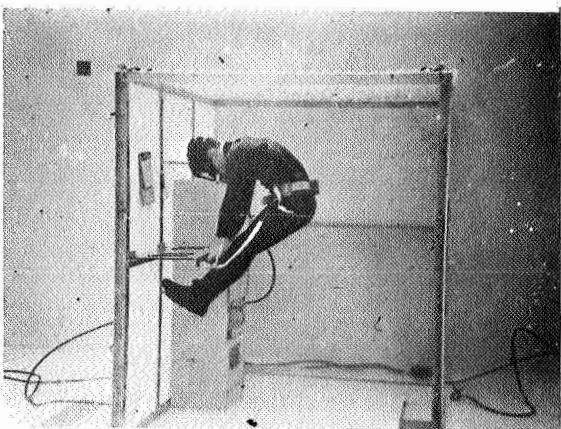


Figure 12.- IVA waist restraint.

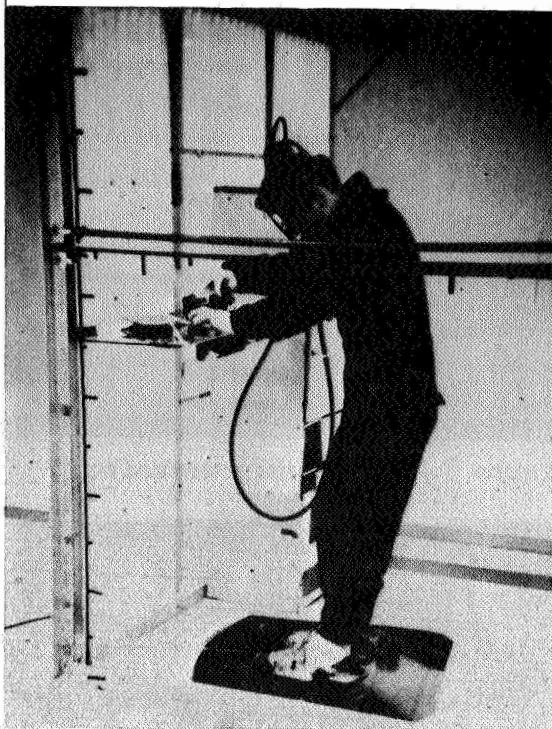


Figure 13.- IVA foot restraints.

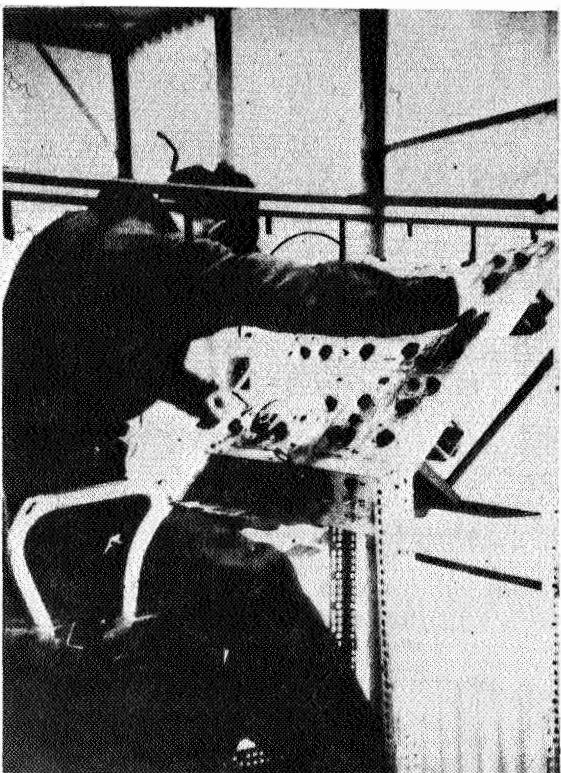


Figure 14.- Chair and safety belt.



Figure 15.- Exercise mode.